AD-A162 768 MEASUREMENT OF HORIZONTAL STRUCTURES AND WAVELENGTHS (5-500 KM) IN MESOSP (U) UTAH STATE UNIV LOGAN CENTER FOR ATMOSPHERIC AND SPACE SCIEEC G W ADAMS 30 AUG 85 1/1

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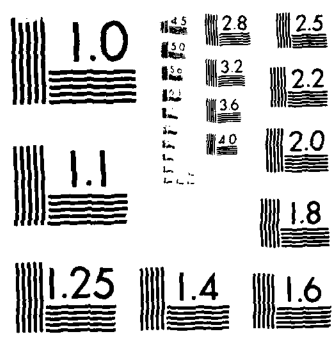

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It is well known that monostatic radars are poor meteor-wind radars. It has been suggested, however, that an outboard receiving site, configured as an interferometer, could receive pulses scattered by meteor trails from the ST's beams, resolve the geometry, and thus measure winds in the 80 - 110 km region. This approach, dubbed MENTOR (Meteor Echoes; No Transmitter, Only Receivers), would be an inexpensive way to add mesospheric capabilities to ST

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radars. The cost of a MENTOR re...iver system is expected to be a small fraction of the cost of either a meteor-wind system or an ST radar. In addition, locations such as Colorado and Pennsylvania that have networks of ST radars could use a single MENTOR receiving site to determine winds above all ST radars within a several hundred kilometer radius. This could make possible the measurement of gravity-wave phenomena over much larger horizontal distances than can be accomplished from a single site. A MENTOR workshop was held 21 May 1984. It was concluded that the MENTOR approach in Colorado (or anyplace else with a network of MST radars) would yield important new information about winds in the mesosphere and about mesospheric gravity waves with horizontal scales of 50-500km. Final Report, AFOSR-84-0121, MEASUREMENT OF HORIZONTAL STRUCTURES AND WAVELENGTHS (5-500 km) IN MESOSPHERIC GRAVITY WAVES, TIDES AND WINDS -- WORKSHOP & DESIGN STUDY

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October 19, 1983

Jerry Ditburner, Lt. Col., USAF
Program Manager
Directorate of Chemical and Atmospheric Sciences
Department of the Air Force
Air Force Office of Scientific Research
Bolling Air Force Base, DC 20332

Dear Lt. Col. Ditburner:

I was funded by Lt. Col. Cress for a study of a method for measuring mesospheric winds and gravity waves, using pulses from existing MST radars that are scattered out of the MST's beams by meteor-ionization trails. An existing network of MST radars in Colorado and a network under construction in Pennsylvania make this an excellent "piggyback" opportunity, one that would result in a mesospheric-wind network capable of measurements of winds, gravity waves, and structures in the mesosphere with scales of 50 - 500 km.

In the course of this study, there were four specific tasks performed:

1) A paper (Attachment #1) was presented at the Second Workshop on Technical Aspects of MST Radar, Urbana, Illinois, May 21 - 25, 1984. This paper was presented as a separate session at the Workshop so that there could be more interaction with and input from the rest of the MST community, and that goal was achieved. The presentation described the basic concept, and established many of the geometrical constraints and relationships.

2) A design study for the MENTOR system was completed by Tycho Technology, Inc., of Longmont, Colorado. Tycho Technology is the only commercial source of MST radars. John Brosnahan, the president and owner of Tycho Technology, is an active participant in much of my research. Tycho Technology's report is Attachment #2.

3) Bob Roper (Georgia Institute of Technology) investigated the potential gravity-wave spectral region that would be accessible with the MENTOR approach. A report on this topic is Attachment #3.

4) John Olivero (Pennsylvania State University) considered the particular problems of establishing a MENTOR network in Pennsylvania that would make use of the MST network being developed there. His report is Attachment #4.

We have determined a number of positive aspects to the MENTOR approach:

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1) Since the MST networks are being sited with many of the same scale interests as MENTOR (albeit in the troposphere), the MST network spacing is excellent for mesospheric measurements.

2) The geometry of the Colorado MST network is such that MENTOR sites are available that have no awkward or ambiguous orientations relative to any of the MST beam configurations. This is by design, not by accident, since the MENTOR project was anticipated and accomodated during the deployment of the Colorado MST network, thanks to the cooperation of Dick Strauch (NOAA/ERL/WPL).

3) The MENTOR approach is capable of measurements of a broad range of horizontal scales that are inaccessible by other measurement techniques in any practical fashion.

4) The design study indicates that the hardware required to implement the MENTOR measurements is straightforward. Our original budget estimates were found to be reasonably accurate.

We have also identified issues that would argue against the pursuit of the two (Colorado and Pennsylvania) networks as originally envisaged. These are:

1) The radar and infrared-optics measurement program that has been operated at the Boot Lake, Colorado, field site has been incorporated into the MAPSTAR program being directed by Russ Armstrong (AFGL). The anticipated interaction between this program and the MENTOR measurements was a strong impetus for my pursuit of the MENTOR concept.

2) One of the three Pennsylvania radars is being constructed to operate at 400 MHz, rather that 50 MHz like the other two. 50 MHz is as high a frequency as is useful for meteor-wind measurements; 400 MHz is not even marginally usable. Therefore only two, rather than three, mesospheric wind vectors could be determined with this network.

In conclusion, the MENTOR approach in Colorado (or anyplace else with a network of MST radars) would yield important new information about winds in the mesosphere and about mesospheric gravity waves with horizontal scales of 50 - 500 km. If you desire that we pursue this work, we shall be happy to do so.

Sincerely yours,

Gene W. Adams

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ATTACHMENT # 1

CENTER FOR ATMOSPHERIC AND SPACE SCIENCES
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April 27, 1984

Dear Colleague:

A small working group has been exploring a possible method for meteor-wind measurements using existing ST radars. A workshop will be devoted to this topic at the upcoming MST Workshop in Urbana, May 21-25. This letter is to sketch the proposed method and to invite you to participate in the workshop.

As you know, monostatic radars are poor meteor-wind radars. It has been suggested, however, that an outboard receiving site, configured as an interferometer, could receive pulses scattered by meteor trails from the ST's beams, resolve the geometry, and thus measure winds in the 80 - 110 km region. This approach, dubbed MENTOR (Meteor Echoes; No Transmitter, Only Receivers), would be an inexpensive way to add mesospheric capabilities to ST radars. The cost of a MENTOR receiver system is expected to be a small fraction of the cost of either a meteor-wind system or an ST radar. In addition, locations such as Colorado and Pennsylvania that have networks of ST radars could use a single MENTOR receiving site to determine winds above all ST radars within a several hundered kilometer radius. This could make possible the measurement of gravity-wave phenomena over much larger horizontal distances than can be accomplished from a single site.

The MENTOR workshop will be held Tuesday evening during the Urbana conference. The location will be posted at the conference. We look forward to seeing you there.

Sincerely yours,

Gene W Adams

Gene W. Adams

Working Group members:

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MENTOR -- ADDING AN OUTLYING RECEIVER TO AN ST RADAR FOR METEOR-WIND MEASUREMENTS

Working Group Draft -- 4/27/84

1. Introduction. Radar scattering from ionized meteor trails has been used for many years as a way to determine mesospheric winds. Scattering occurs perpendicular to the trail, and horizontal trails are rare, so virtually all meteor-wind radars are bistatic. ST radars, being monostatic, get few usable returns from meteor trails in the mesosphere (although Avery and coworkers have successfully retrieved meteor winds from the Poker Flat, Alaska, MST data).

It has been suggested that a receiving station some distance from an ST radar could receive pulses being scattered from meteor trails, determine the particular ST beam in which the scattering occurred, measure the radial Doppler velocity, and thus determine the wind field. This concept has been named MENTOR (Meteor Echoes; No Transmitter, Only Receivers). This paper is a preliminary look at system requirements and possibilities.

There are a number of immediate questions to be answered, such as: If we receive a pulse scattered from an ST beam, how can we tell which beam it's from? How can we measure the Doppler velocity without access to the ST's oscillator? Can we also measure the altitude of scattering? Can we use this information to determine the wind field? In this paper we sketch one possible approach to these questions.

2. Site Location. Consider a typical ST radar with 3 beams; one vertical, one steered 15 degrees due North, and the third pointed 15 degrees East, as shown in Figure 1.

Many ST's forego the vertical beam, and with it the ability to measure vertical winds. The MENTOR approach probably can't measure vertical winds anyhow, but viewing the third beam of an ST radar will increase the MENTOR rate by 50%. If all three ST beams use a common frequency, no additional hardware is required.

For the geometry shown in Figure 1, the best location for a MENTOR site is probably along a NE - SW line, so that the three ST beams can been seen from the MENTOR site as three separate beams with maximal separation. We will consider two MENTOR sites; one 100 km from the ST site and one 300 km from the ST site.

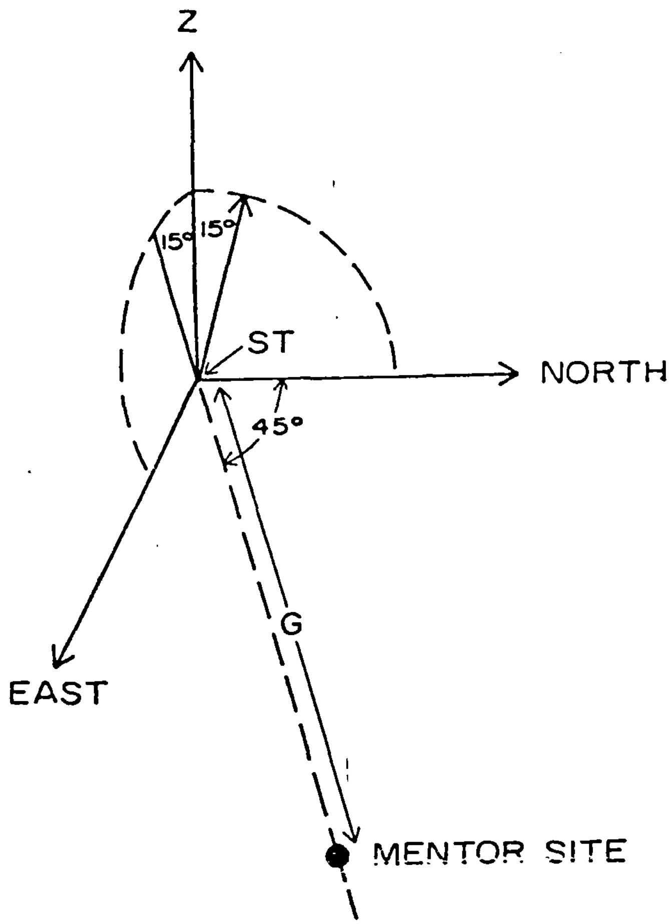


Figure 1. ST CONFIGURATION AND MENTOR SITING

3. ST Beam Determination. Consider a pair of MENTOR antennas defining a line normal to the MENTOR - ST axis. Let D be the spacing between the two antennas. Then the horizontal projection of the geometry is as shown in Figure 2. (This figure actually shows the horizontal projection for a MENTOR site located to the SW, rather than NE, of the ST site.) We want to choose D so that the spacing of the ST beams maps into, say, 90 degrees phase difference between this pair of MENTOR antennas.

Take the altitude region of interest to be 95 ± 15 km, and ignore effects due to the Earth's curvature. Assume an ST frequency of 50 MHz, so that = 6 meters. Let the ST-to-MENTOR distance be G (= either 100 or 300 km for the two strawman locations we have chosen.) Then we get

$$a = 95 \tan(15^{o}) = 25.5 \text{ km}$$

$$b = c = a/\sqrt{2} = 18 \text{ km}$$

$$\alpha = 2\tan^{-1}\left(\frac{c}{G+b}\right) = 17.3^{\circ} \ (G = 100 \text{ km})$$

$$= 6.5^{\circ} \ (G = 300 \text{ km})$$

$$\Delta\phi = \frac{2\pi D}{\lambda}\sin\alpha$$

Thus we find the desired spacing of the transverse pair of antennas to be 10.1 meters for the near site and 26.5 meters for the far site. With this spacing, the phase difference across the antennas will be 0 degrees if the received pulse originated in the ST's vertical beam, +90 degrees if it came from the ST's North beam, and -90 degrees if it came from the ST's East beam. The range of altitudes (+/- 15 km) maps to a spread in the phase-difference values of +/- 25 degrees.

Some ST's operate using different frequencies on different beams to improve beam separation. This makes beam identification easy, but means that two MENTOR channels are needed at each ST frequency for altitude determinations.

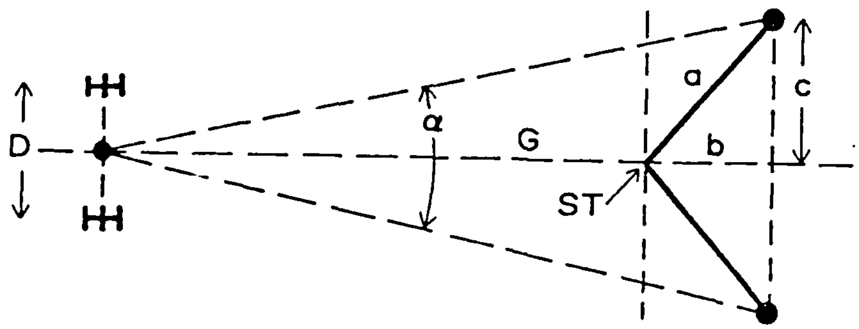


Figure 2. BEAM-DETERMINATION GEOMETRY

4. Altitude Determination. For altitude determinations, we need an antenna (and receiver channel) to form a longitudinal pair with one of the first two antennas. Now consider the phase difference across this pair of antennas for an echo from the vertical beam at an altitude z, as shown in Figure 3.

$$\Delta\phi = \frac{2\pi D}{\lambda}\sin\left[\tan^{-1}\left(\frac{Z}{G}\right)\right]$$

Thus we can choose the separation of the altitude-determining pair of

antennas so that the expected range of altitudes (80 - 110 km) is mapped into phase differences from, say, 0 to 90 degrees. This will give an altitude resolution of 0.5 km with the anticipated MENTOR phase resolution of 1.5 degrees (slightly better or worse for the tipped beams, depending on which way they're tipped). Notice that no time-of-flight information about the pulse is needed for the altitude determination.

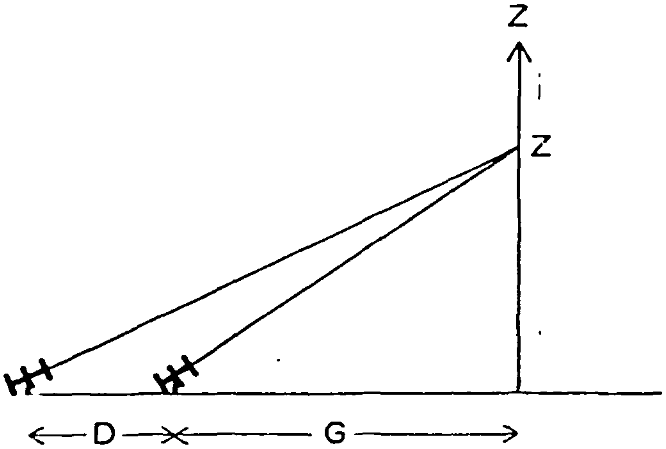


Figure 3. ALTITUDE-DETERMINATION GEOMETRY

If it is neccessary to operate the MENTOR receiver from a site such that two of the ST's beams are too closely coplanar (a projected separation of less than, say, 3 degrees), then the transverse pair of MENTOR antennas cannot discriminate between the overlapped pair of ST beams. However, if the MENTOR site is close enough to the ST site so that the regions lying between 80 and 110 km don't overlap in projection, then the longitudinal pair of MENTOR antennas can resolve the overlapped pair of ST beams. This is sketched in Figure 4. From the geometry shown,

$$x = 110 \tan(15^{\circ}) = 29.5 \text{ km}$$

$$\theta_L = \tan^{-1}\left(\frac{110-80}{x}\right) = 45.5^{\circ}$$

$$G_L = \frac{80}{\tan \theta_L} = 78.6 \text{ km}$$

The limiting ground distance is 78.6 km; beyond that, it would be necesary to add logic to MENTOR to determine the time-of-flight of the pulse from the ST, and use that information to determine which beam the pulse came from. We will not consider this case further.

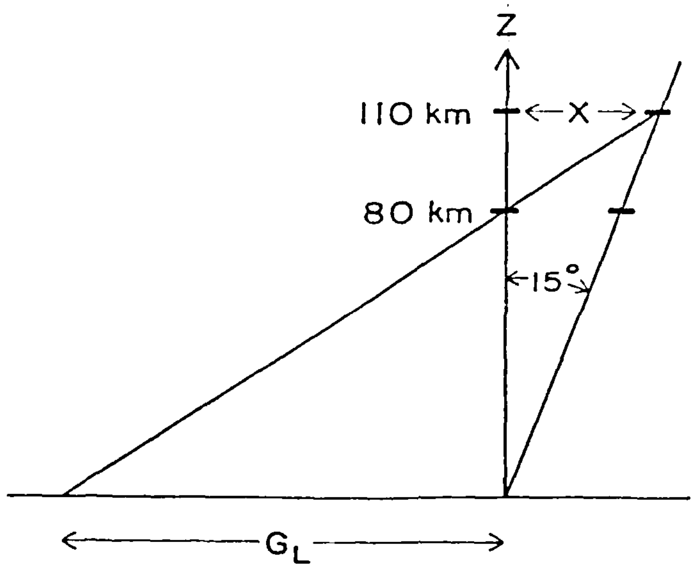


Figure 4. LIMITING GEOMETRY FOR OVERLAPPED BEAMS

5. Radial Doppler Frequency Determination. MENTOR will use, as do the ST radars, coherent detectors, so that both quadrature components of the signal (and thus amplitude and phase) are measured. This gives both the magnitude and the sign of the Doppler velocity. The problem of determining the radial Doppler velocity becomes the problem of determining $d\phi/dt$, with ϕ measured every pulse over a typical meteor-trail lifetime of 1/3 second. At the ST's pulse rate of 217 pulses/second, this will yield 72 measurements of the phase over the lifetime of the signal. If we take 150 m/sec to be a likely upper limit to the radial component of the mesospheric wind speed, then the maximum $d\phi/dt$ will be 83 degrees/pulse, which is extreme, but measureable.

6. Reference Oscillator Stability. The remote measurement of meteor echoes as envisaged here requires good oscillator stability for both the ST transmitter and the MENTOR receivers. Even good commercial oscillators have enough aging drift that frequent recalibration would be needed. However, commercial WWVB phase-lock receivers are available at moderate cost. Retrofitting existing ST's appears to be no problem. The velocity error due to frequency instability will thus be <1 m/sec.

7. Wind Velocity Determination. Operation of the MENTOR system will be similar to other meteor-wind radars; meteor echoes and their characterizations will be accumulated until all three beams are well sampled in as many altitude bins as possible, commensurate with the wave periods of interest. A three-dimensional wind vector can then be fitted to the data. An ST radar uses one beam that is carefully verti-

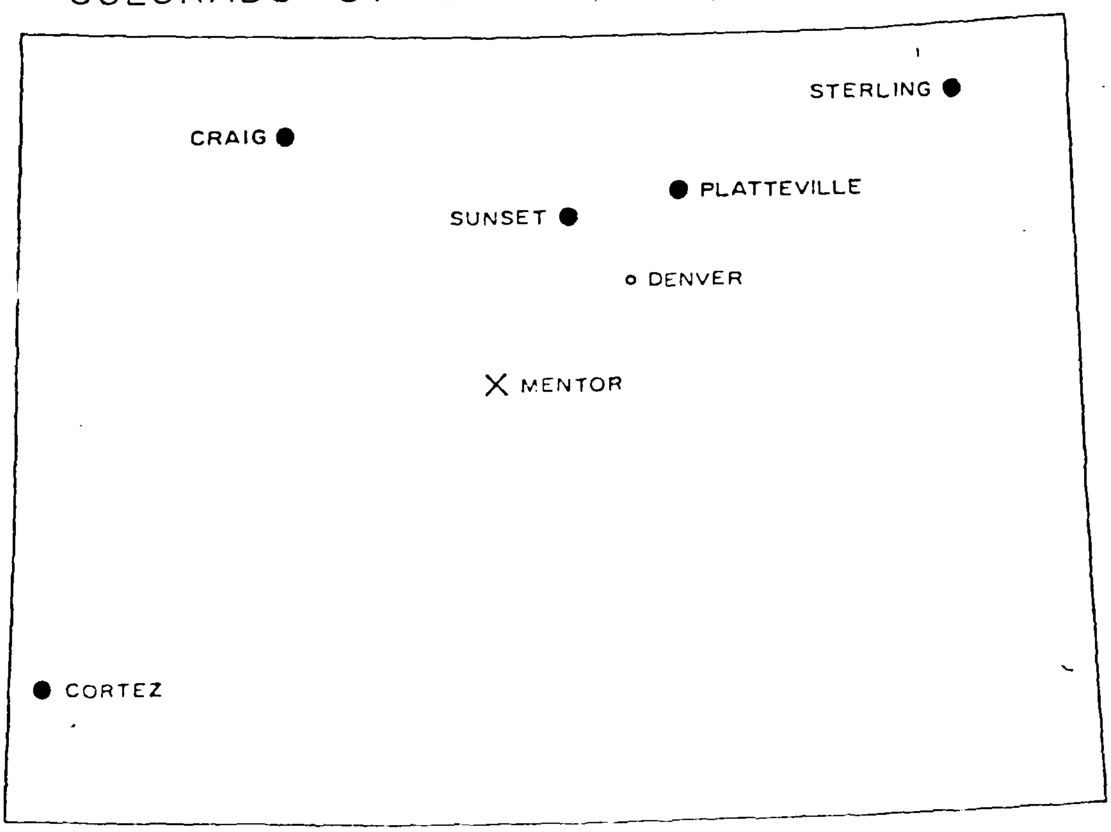
cal, since a typical vertical velocity is overwhelmed by even a small component of the (usually) much-larger horizontal velocity. The geometry of the MENTOR system appears to preclude vertical velocity measurements, or at least to render them difficult. It is also clear that the error of the horizontal wind determination will increase as the MENTOR - ST spacing increases. The error goes as

$$\frac{\sqrt{G^2+Z^2}}{Z}$$

so that the error will be 40% larger than the "ST equivalent" at the near site (G = 100 km) and x3.2 larger at the far site (G = 300 km).

8. Network Possibilities. There are two areas, Colorado and Pennsylvania, where networks of ST radars are operating (or soon will be). It is feasible to operate a single MENTOR receiving site to monitor meteor winds above a number of ST radars, provided they're all within, say, 500 km of a common site. (Received signal strength is the limiting parameter). The Colorado network is shown in Figure 5. The ST radar sites now operating are shown as large solid circles; a likely MENTOR site is indicated. This site would give a maximum ground distance of 310 km to the furthest ST site. The differential cost for monitoring an additional ST radar, once the initial MENTOR system is installed, is expected to be small.

COLORADO ST NETWORK



9. Summary and Conclusions. Meteor-wind measurements can be made by siting a three-channel receiver some distance from an ST radar, then measuring Doppler velocities from meteor-trail scattering of the ST's pulses. Much of the gravity wave activity in the mesosphere is thought to occur with horizontal wavelengths of 10 to 1000 km. A single MENTOR site in Colorado or Pennsylvania could add useful information over much of this range. We are working on data-rate calculations and system design. These will be discussed at Urbana.

Preliminary tests have shown adequate echo rates for tidal and longer period winds to be determined from at least three of the Colorado Network stations. At least two more will be available with the installation of larger receiving arrays. It is doubtful that sufficient echoes will be obtained from individual stations for short period (less than 1 hour) gravity wave structures to be determined directly. However, a technique is being developed which, by subtracting the hourly mean profiles from the individual line of sight doppler drifts, will enable a statistically significant determination of the absolute energy content and spatial and temporal decorrelations of the total random wind spectrum.

Continuous records, such as those produced by the Georgia Tech Radio Meteor Wind Facility, provide ample evidence of a synoptic meteorology at mesopause altitudes (see, for example, Salby and Roper (1980) and Dolas and Roper (1981), copies attached). By including the spatial variability measured by MENTOR, questions relating to the decorrelation scales, in addition to the decorrelation times measured by the single site technique, for both the tidal oscillations and the shorter period gravity waves can be answered, and these can be related to the synoptic circulation. MENTOR is unique in its ability to determine horizontal structure as a function of height. Previous experiments, using a single site radar with antennae pointing in various directions, such as those performed in the Soviet Union, have produced results which cannot be sensibly interpreted since echo height was not measured.

From Dr. R.G. Roper

ATTACHMENT # 4

THE PENNSYLVANIA STATE UNIVERSITY

503 WALKER BUILDING
UNIVERSITY PARK, PENNSYLVANIA 16802

College of Earth and Mineral Sciences
Department of Meteorology

Area Code 814
865-0478
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October 15, 1984

Dr. Gene Adams
Center for Atmospheric and Space Science
UMC 34
Utah State University
Logan, Utah 84321

Dear Gene;

I wish to thank you for the opportunity to interact with you, Brosnahan, and Roper in Project MENTOR. I feel we all benefited from the technical discussions and made the MST radar community aware of an interesting alternative measurement configuration.

Spending my sabbatical year in Boulder made it easy for me to interact with John Brosnahan and especially, to get out to the Boot Lake site to observe the meteor trail scattered signals. Having the least radar experience within the group, myself, this was quite helpful.

The MST Radar Workshop held at the University of Illinois in late May 1984 was the high point of this experience for me. The MENTOR workshop/session was well attended and generated spirited discussions. The general impression of the group was that this new technique was quite promising and deserved a try.

I deeply appreciate the opportunity to be a part of the MENTOR study.

Sincerely yours,

John J. Olivero
Associate Professor of Meteorology

JJO:dc

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